

EFFECTS OF GROWING PLANTS ON HUMUS AND PLANT RESIDUE DECOMPOSITION IN SOIL;  
UPTAKE OF DECOMPOSITION PRODUCTS BY PLANTS

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SUMMARY

Phytotron studies were conducted to evaluate the effect of growing corn plants (*Zea mays* L.) on soil organic constituent decomposition. Soils, in plastic pots, were amended with either <sup>14</sup>C-labeled plant residues, soil organic matter, or lignin and either planted or left unplanted. The temperature and moisture conditions of the soil-plant system were carefully controlled. The total and <sup>14</sup>CO<sub>2</sub> evolved from the pot headspace was monitored throughout the growth period. At indicated times, plants and soils were destructively sampled and analyzed for their <sup>14</sup>C content. Growing plants did not significantly affect plant residue mineralization but did decrease the amount of labeled organic matter or lignin remaining in the soil. Little <sup>14</sup>C was taken up by plants growing in a soil in which plant residues were decomposing. <sup>14</sup>C uptake was somewhat higher when plants grew in a soil with labeled soil organic matter and was significantly higher in a soil amended with <sup>14</sup>C-lignin. Significant amounts of the absorbed <sup>14</sup>C were translocated from the roots into the sprouts.

INTRODUCTION

Humus is in a steady state equilibrium of formation and degradation. This equilibrium can be shifted to one side or the other by climatic factors or by soil management and cropping practices. Despite their complex nature and their commonly accepted structural resistance against microbial decay, humic compounds, once their intimate association with metal ions or clays or within aggregates is disturbed, are then more prone to microbial decay (ref. 1). Growing roots may disturb this association of humic compounds with inorganic compounds or within the aggregates (ref. 2). They also may cause an additional "priming" effect due to root deposits which can lead to changes in the microbial activity of the rhizosphere (refs. 3, 4). Roots also can influence the chemical composition of the soil they contact by absorption of nutrients, particularly of nitrogen. Furthermore, root uptake of water may create more rapid wetting and drying effects which enhances soil organic matter degradation (refs. 5, 6).

The present study, about the effects of growing corn plants on carbon mineralization, originated from several previous observations. Phytotron experiments, where soil in containers was fertilized with <sup>15</sup>N-labeled mineral

N indicated an apparently higher mineralization of soil organic N in planted compared with unplanted soil (refs. 7, 8). It was questionable whether or not this apparently higher N-mineralization was also accompanied by an enhanced C-mineralization in a planted soil. Other observations indicated that ligninolytic organisms isolated from soil were also active in the degradation of humic compounds (ref. 9). Since both degradation of lignin and humic acids was enhanced at low nutrient N-concentrations, we theorized that lower mineral N concentrations as they may occur in a rooted soil, also might positively affect organic matter mineralization.

Reports in the literature about the effects of growing plants on organic carbon mineralization are, however, contradictory. Several authors (refs. 10 - 13) suggest that native soil or plant residue carbon mineralization in a planted soil proceeds faster than in a complementary unplanted soil. Conversely, Shields and Paul (ref. 14), Sparling et al. (ref. 15), Reid and Goss (refs. 16, 17) and Martin (ref. 18) found in experiments with  $^{14}\text{C}$ -labeled materials that growing plants tended to conserve carbon from added plant residue material or from native soil. It was, however, also observed that the lower rate in  $\text{CO}_2$ -evolution due to plantation was partly compensated by the uptake of labeled carbon into roots (ref. 15) and transport into the sprouts (ref. 18). Due to our interests of whether or not humus can have an "indirect" effect on plant growth (ref. 19) by the uptake of low molecular weight substances, we also were eager to get further information about this question.

## METHODS

In two sets of experiments, plastic containers were filled with 17.4 kg of dry soil (Typic Hapludalf silt loam, parabrown soil from Bodenstedt, West Germany) which was carefully mixed before with  $1 \text{ g} \cdot \text{kg}^{-1}$  of powdered uniformly  $^{14}\text{C}$ -labeled wheat or corn straw material ( $0.43$  and  $0.32 \text{ MBq} \cdot \text{g}^{-1}$ , respectively). Four replicates for each amendment were planted with two corn seedlings (14 day old) and 4 were left unplanted. Both planted and unplanted replicates were fertilized with mineral N. The soil surface was covered with gravel and a paraffin-vaseline mixture sealed the pot headspace from the surrounding atmosphere (see Fig. 1). The pots were placed in a phytotron, maintained at  $23^\circ\text{C}$  and illuminated for  $16 \text{ h} \cdot \text{day}^{-1}$  at about  $80 \text{ W} \cdot \text{m}^{-2}$ . The total and the  $^{14}\text{CO}_2$  evolved from the soil was continuously purged from the pot headspace by pulling air through  $1 \text{ N}$  NaOH solution and determined by titration and scintillation counting.

The water supply system allowed a careful control for an equal water regime in both planted and unplanted replicates (ref. 20). Water was added to the soil of each pot by two vertically installed ceramic candles. These were connected by water filled flexible tubes to a water storage bottle outside

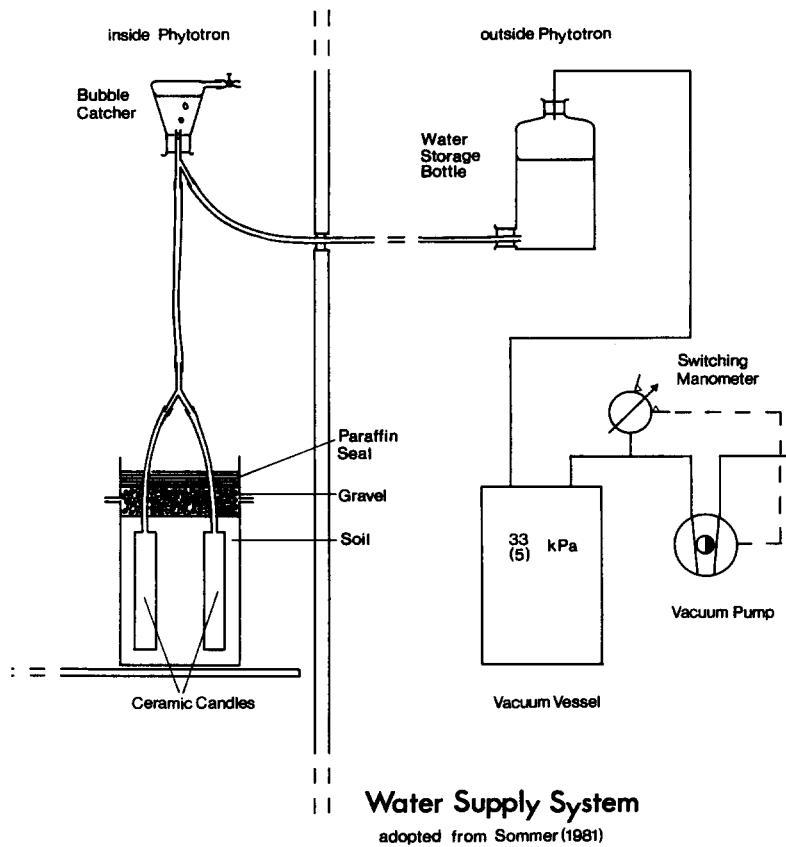


Fig. 1. Arrangement of the pots and the controlled water supply system for soil and plants in the phytotron

the phytotron. A constant negative air pressure above the water surface could be maintained by a manometer with adjustable electrical contacts. The large vessel was used to buffer pressure changes. Whenever the adjusted negative pressure was impaired by intruding air, a vacuum pump started to work and the negative pressure was reestablished to the desired level. Normally the soil water tension was kept at -33 kPa (60 % WHC). The system also allowed water tension variations and to simulate wetter or dryer conditions. When the manometers were set to gain low moisture tension, water flowed into the soil from the storage bottles and was sucked back by setting the manometers to gain higher moisture tensions. The actual water content in the soil was additionally monitored by registering tensiometers with an electrical signal exit. Further details of the phytotron setup and the irrigation system have been described (ref. 21).

A separate but similar study was conducted to investigate the effect of growing plants on mineralization of native soil carbon. For this study, soil was used which was incubated before for 190 days with  $^{14}\text{C}$ -labeled wheat straw at room temperature and 60 % WHC. After this time it had lost 65 % of the originally added  $^{14}\text{C}$  as  $\text{CO}_2$ . Eleven hundred g of this soil was filled into 1 L containers which ensured air tight separation and control of the root zone (ref. 22). Five replicate pots were planted with one 14 day old corn seedling and 5 were left unplanted. The plants were sealed into the lid of the pot along with separate tubes for air in- and outlet. A constant water potential was maintained at -33 kPa by a similar control system as described before, but using smaller ceramic candles. Evolved  $\text{CO}_2$  and  $^{14}\text{CO}_2$  was collected and measured during a 33 day growing period. After harvest  $^{14}\text{C}$ -activity was determined in the sprouts, roots and in the soil. The roots were carefully rinsed with water and with 0.01 N NaOH to remove adherent soil material.

Similar small pot studies were made to observe the effect of plantation on the mineralization of lignin. This material was applied as corn straw, specifically  $^{14}\text{C}$ -labeled in the aromatic rings or the methoxyl group of the lignin portion (9.0 and 11.5  $\text{KBq} \cdot \text{g}^{-1}$ , respectively). This material was prepared by infiltration of growing corn plants with ring- or methoxyl-  $^{14}\text{C}$ -labeled ferulic acid in a very dilute aqueous solution (ref. 23). For other experiments also DHP-lignin was used; this was prepared by polymerisation of coniferyl alcohol with peroxidase and  $\text{H}_2\text{O}_2$ . The coniferyl alcohol was also either  $^{14}\text{C}$ -ring or methoxyl labeled (ref. 24). The  $^{14}\text{C}$ -activity in the DHP-lignin was 20  $\text{KBq} \cdot \text{mg}^{-1}$  for the ring- and 18.3  $\text{KBq} \cdot \text{mg}^{-1}$  for the methoxyl-labeled DHP. In these experiments 1100 g of soil was mixed with 1.5 g of lignin labeled corn straw or with 180 mg of labeled DHP. Five replicates of each lignin amended soil were planted and five were left unplanted. The  $\text{CO}_2$  and  $^{14}\text{CO}_2$  evolution was measured for 33 days and then the  $^{14}\text{C}$  activity was determined in sprouts, roots and soil.

## RESULTS AND DISCUSSION

### Decomposition of added wheat or corn straw materials

Wheat or corn straw materials decomposed at essentially the same rates in planted or unplanted pots if the soil water tension was constantly kept

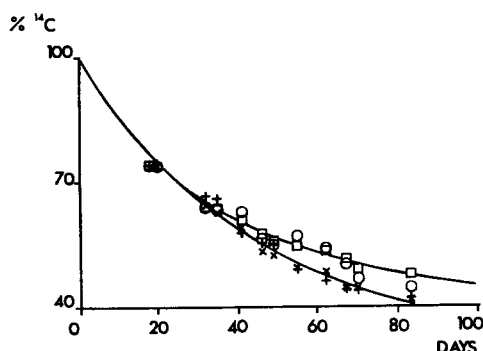


Fig. 2. Decomposition of u- $^{14}\text{C}$  wheat straw in unplanted (x--x) and planted soil (+--+), decomposition of u- $^{14}\text{C}$  corn straw in unplanted (o--o) and planted (□--□) soil. The  $^{14}\text{CO}_2$  evolution is expressed as % of the total  $^{14}\text{C}$  added to soil.

at -33 kPa (see Fig. 2). Growing plants therefore did not significantly alter the decomposition rate of plant residues. Slight differences in the decomposition rate of both plant residues could be seen only at the end of the experiments. In planted and unplanted soil,  $52 \pm 5\%$  of  $^{14}\text{C}$  from both residues had evolved from the soil after 83 days. Another set of experiments was made where soil moisture tension was set for 3 days at -33 and for another 4 days at -60 kPa. The pot to pot variation in  $^{14}\text{CO}_2$  production was greater than that at constant soil water tension. The total  $^{14}\text{CO}_2$  evolution from planted replicates, however, was somewhat higher than that from the unplanted samples ( $P \geq 0.05$ ). We are, however, not sure if this higher  $\text{CO}_2$  evolution was an effect of plantation or if the wetting and drying caused this enhanced degradation of the plant residue material in the planted soil.

### Effect of plantation on the decomposition of lignin on soil humus

In additional small pot studies, soil was amended with ring- or methoxyl- $^{14}\text{C}$ -labeled lignin in the form of corn stover or DHP. They showed, at constant soil water tension, that less  $^{14}\text{CO}_2$  was evolved from planted than from unplanted pots (Fig. 3). These differences were statistically significant at the  $P \leq 0.01$  level. After 23 days the highest amount of  $^{14}\text{CO}_2$  was lost from the methoxyl labeled lignin and this amounted to 35 % from the unplanted and 27 %

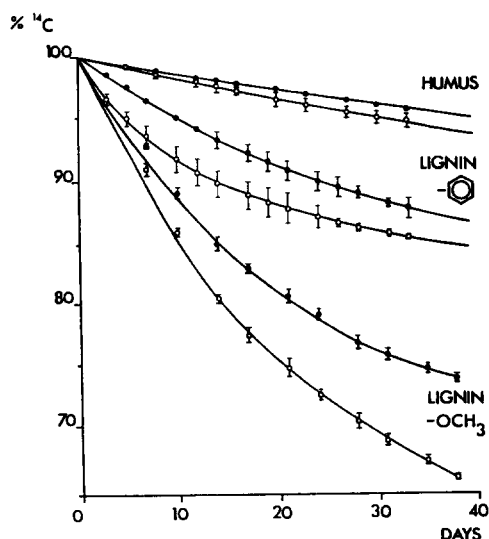


Fig. 3. Decomposition of  $^{14}\text{C}$ -labeled soil organic matter, of ring- and methoxyl- $^{14}\text{C}$ -labeled lignin. Planted soil (●--●), unplanted soil (○--○)

from the planted soil. For the ring labeled lignin these losses amounted to 16 and 12 - 13 %, respectively. The  $^{14}\text{CO}_2$ -evolution from both lignin preparates (corn straw or DHP-lignin) was very similar for the corresponding labelings.

When plants grew in a soil where the soil organic matter was uniformly labeled with  $^{14}\text{C}$ , a small but not statistically significant different reduction ( $P \geq 0.05$ ) in the  $^{14}\text{CO}_2$  release was observed from the planted compared to the unplanted soil (see Fig. 3). The total  $^{14}\text{C}$  evolved during the 33 day growing period was very small and amounted  $4.6 \pm 0.3$  % for the planted and  $5.4 \pm 0.6$  % for the unplanted soil, respectively.

Martin (ref. 18) reported a more retarding effect of plantation on  $^{14}\text{CO}_2$  release from labeled soil organic matter. This retarding effect, however, disappeared if the same soil was reincubated for a second time with or without plantation. The differences in his and our observations might be explained, if it is assumed that the soil used in his experiments contained more of only slightly modified lignin material than ours. This material decomposed during the first growing cycle and therefore, the resulting  $^{14}\text{CO}_2$  evolution in the second growing cycle was more equal from planted and unplanted soils. The greater retardation of  $\text{CO}_2$ -evolution from labeled soil organic matter due to plantation as observed by Sparling et al. (ref. 15) might be explained similarly. In his experiments, however, the experimental design was different and he also used barley instead of corn plants.

# Uptake of labeled carbon compounds by plants

$^{14}\text{C}$ -analyses of the corn tops and roots after growing plants in a soil amended with  $^{14}\text{C}$ -labeled plant residue materials indicated that very little

TABLE 1

Effect of growing corn plants on  $^{14}\text{CO}_2$  release from uniformly  $^{14}\text{C}$ -plant residue material and from  $^{14}\text{C}$ -soil organic carbon. Uptake of  $^{14}\text{C}$  by roots and sprouts. Means and standard deviation from 4 - 5 replicates, each.

	From plant C <sup>1</sup>		From soil organic C <sup>2</sup>	
	Planted	Unplanted	Planted	Unplanted
	<----- mg $^{14}\text{C}$ /pot ----->			
$^{14}\text{CO}_2$ Evolv.	3550 $\pm$ 56	3660 $\pm$ 120	7.6 $\pm$ 0.5	8.9 $\pm$ 0.9
$^{14}\text{C}$ in Roots	3.4 $\pm$ 1.2		0.9 $\pm$ 0.2	
$^{14}\text{C}$ in Tops	48.5 $\pm$ 8.3		0.2 $\pm$ 0.15	
$^{14}\text{C}$ in Soil	2800 $\pm$ 100	2650 $\pm$ 150	136 $\pm$ 11	137 $\pm$ 5

<sup>1</sup>From experiments with addition of uniformly labeled wheat straw (6.44 g C to 17.4 kg of soil).  $^{14}\text{C}$  distribution after 83 day growing period

<sup>2</sup>1100 g soil contained 143 mg  $^{14}\text{C}$  in soil organic matter.  $^{14}\text{C}$  distribution after 33 day growing period

$^{14}\text{C}$  was absorbed by the plants (Table 1). Only 1.5 % of the mineralized  $^{14}\text{C}$  was incorporated into the tops and less than 0.1 % into the roots. This agrees with reports by Führ and Sauerbeck (ref. 22) who also observed a very small incorporation of  $^{14}\text{C}$  from rotted plant residues by *Daucus carota*.

Also the uptake of labeled carbon from soil organic matter by the growing corn plants (Table 1) was very small. This uptake was significantly more, when plants grew in a soil amended with labeled lignin (Table 2). If the lignin was labeled in the aromatic rings, this amount was similar to that evolved as  $\text{CO}_2$  and more  $^{14}\text{C}$  was found in sprouts than in the roots. In the case of  $^{14}\text{C}$ -methoxyl labeled lignin, the uptake was less than the  $^{14}\text{CO}_2$  evolution. The amount of lignin derived carbon absorbed by the plants from both labelings ( $^{14}\text{C}$ -ring or -methoxyl) was about the same. This indicates that plant roots can take up small amounts of organic decomposition products from lignin and these are also transported into sprouts. If this absorbed C is added to the C evolved as  $\text{CO}_2$ , this should indicate an enhanced degradation of lignin due to plantation. However, we do not know whether a similar lignin fraction as absorbed by the plants was immobilized in an unplanted soil.

TABLE 2

Effect of growing corn plants on  $^{14}\text{C}$  release from corn straw material, specifically labeled in the lignin portion by  $^{14}\text{C}$  in the aromatic rings and the  $\text{OCH}_3$ -group, respectively. Means and standard deviation from 5 replicates, each.

	From lignin $^{14}\text{C}$ ring <sup>1</sup>		From lignin $^{14}\text{C}$ $\text{OCH}_3$ <sup>1</sup>	
	Planted	Unplanted	Planted	Unplanted
	<----- mg $^{14}\text{C}$ /pot ----->			
$^{14}\text{CO}_2$ Evolv.	24.9 $\pm$ 1.7	29.5 $\pm$ 2.0	53.6 $\pm$ 4.2	70.0 $\pm$ 4.8
$^{14}\text{C}$ in Roots	4.0 $\pm$ 0.4		2.0 $\pm$ 0.8	
$^{14}\text{C}$ in Tops	16.5 $\pm$ 2.1		18.5 $\pm$ 1.2	
$^{14}\text{C}$ in Soil	150 $\pm$ 6	169 $\pm$ 4	122 $\pm$ 15	123 $\pm$ 24

11.5 g corn straw material contained about 200 mg C in the lignin fraction.  $^{14}\text{C}$  distribution after 33 day growing period

## CONCLUSIONS

At constant and medium soil moisture tensions no significant effect of growing corn plants on the mineralization rates of plant residues compared to an unplanted soil was observed. A retarding effect of plantation, however, was found on the mineralization of lignin. Plantation also retarded mineralization of soil organic matter, but to a lesser and non-significant extent. Our observation therefore agree better with those of Shields and Paul, Sparling et al., Reid and Goss and Martin (refs. 14 - 18). They also reported that plantation has no or even a suppressive effect on carbon mineralization at comparable moisture tensions in a planted or unplanted soil.

The uptake of  $^{14}\text{C}$ -labeled compounds from decomposing plant residues by growing plants was small and amounted to only 1 - 2 % of the mineralized carbon. Relatively more carbon was absorbed from the decomposition products of humus, and the greatest portion from the degrading lignin. This amount was similar from ring- or methoxyl-labeled lignin.

It is improbable that  $^{14}\text{CO}_2$ -uptake by plant roots contributes very much to the observed radioactivity in the plants. We know from former experiments (ref. 25) that little  $^{14}\text{CO}_2$  dissolved in water was taken up by roots and incorporated into sprouts. Roots, however, are capable of taking up a variety of compounds in small amounts (ref. 19). Among them, aromatic and phenolic compounds can have an effect on plant growth. Small amounts of phenols were observed to be released during the microbial degradation of lignin. Uptake of these compounds may explain the "indirect" effect of soil humus and composts on plant growth in promoting higher yields than can be achieved with inorganic fertilizer alone.

When we started our experiments we wanted to investigate whether or not the apparently higher organic-N mineralization from soil organic matter or plant residues in a planted soil was accompanied by a higher carbon mineralization. The present results did not verify that this was paralleled by a higher carbon mineralization due to plantation. We therefore, explain this apparently higher N-uptake to arise from N which is intermediately mineralized by microbes from its organic form and taken up by plant roots. In the unplanted soil, with no competition of plant roots, this mineralized N can be reimmobilized by the microflora. This also should explain the observed higher N-immobilization of added  $^{15}\text{N}$ -labeled fertilizer-N in unplanted soils (ref. 7).

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